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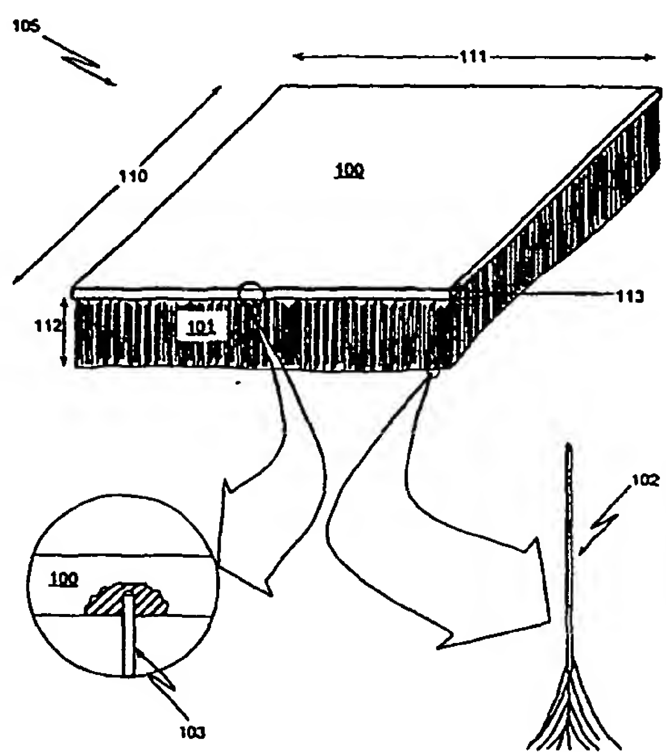
(57) Abstract

A plurality of flexible, parallel, thermally conductive fibers (101) has a first end that is open and a second end embedded into a thermally conductive base (100).



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A FIBROUS THERMAL INTERFACE ADAPTOR

The present invention relates to heat dissipation and more particularly tq a thermal interface that efficiently conducts heat from a heat generator to a heat dissipater.

BACKGROUND

Computer systems, from small handheld electronic devices to medium-sized mobile and desktop systems to large servers and workstations, are becoming increasingly pervasive in our society. Computer systems typically include one or more integrated circuits (ICs) such as one or more processors, controllers, or memory devices. During operation of the computer system, an IC tends to generate heat. If this heat is not adequately removed from the IC, the IC may malfunction. In some cases, the heat will cause the IC to fail, causing computer system failure. Thus, to ensure quality and reliability, a computer designer must provide for proper thermal management of the ICs.

To cool an IC, the heat generated by the IC may simply be dissipated directly from the IC to the ambient environment. If this does not provide adequate cooling, a fan may be used to increase the heat dissipative efficiency. If this still does not provide adequate cooling, devices may be thermally coupled to the IC to further increase the heat dissipative efficiency by, for example, increasing the surface area from which the heat is dissipated, converting the thermal energy to an alternate form of energy, or cooling the ambient environment. Such devices are referred to as heat dissipaters.

To thermally couple a heat dissipater to an IC, a thermal grease is typically used at the interface between the IC and the heat dissipater. The thermal grease is intended to fill any gaps which may exist at the interface. Such gaps, if not filled, represent locations of high thermal resistivity between the IC and the dissipater, lowering the thermal transport efficiency between the two surfaces. One problem with the use of thermal greases is that they tend to separate over time, leaving unfilled gaps behind. This separation occurs because the surface of the IC warps after being packaged at room

temperature, then flattens as the IC heats up during operation. The warping may be caused by mismatched thermal constants of materials used in the IC package or the heat dissipater. The constant warping and flattening of the IC has a tendency to pump the thermal grease out of the interface.

SUMMARY OF THE INVENTION

In accordance with one embodiment of the present invention, a plurality of flexible, parallel, thermally conductive fibers has a first end that is open and a second end embedded into a thermally conductive base.

Other features and advantages of the present invention will be apparent from the accompanying drawings and the detailed description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings in which like references indicate similar elements and in which:

Figure 1 is a thermal interface formed in accordance with an embodiment of the present invention;

Figure 2A is a cross-section of a thermal interface used in a thermal conduction system in accordance with one embodiment of the present invention during a first period of time;

Figure 2B is the cross-section of Figure 2A during a second period of time;

Figure 3 is a cross-section of a thermal interface used in a thermal conduction system in accordance with another embodiment of the present invention;

Figure 4A is a thermal conduction system in accordance with another embodiment of the present invention; and

Figure 4B is the thermal conduction system of Figure 4A after thermal coupling has taken place.

DETAILED DESCRIPTION

In accordance with one embodiment of the present invention, a thermal interface is used to thermally couple an integrated circuit (IC) to a heat dissipater in a computer system. The IC may be any of the various different types of ICs typically found in a computer system, such as a processor, chipset, memory device or controller. The heat dissipater may include a thermal spreader, fan, heat sink, or heat pipe, and generally includes some type of broad, flat, metallic surface to be bonded to a surface of the thermal interface.

The thermal interface includes a plurality of flexible, parallel, graphite fibers. The first end of the fibers is in direct contact with the IC, and the second end is embedded into a thermally conductive base. The first end may have some limited freedom of movement along the surface of the IC or may be embedded into the surface to promote thermal coupling. As the IC heats up and flattens during operation, the fibers flex and bend to accommodate the flattening, maintaining good thermal contact with the IC without forming gaps.

As used herein, the term IC includes not only the semiconductor substrate and circuits formed thereon but also any materials used to package the substrate including, for example, ceramic, plastic, or metal. A more detailed description of embodiments of the present invention, including various configurations and implementations, is provided below.

Figure 1 is a thermal interface 105 formed in accordance with an embodiment of the present invention. Thermal interface 105 includes thermally conductive base 100 into which flexible, parallel thermally conductive fibers 101 are embedded at one end. The fibers are open at an opposite end, meaning that they have some freedom of independent movement because they are not embedded into any material. For one embodiment of the present invention, base 100 is copper and the fibers are graphite. For an alternate embodiment, base 100 may comprise other materials in addition to copper or instead of copp r, and the fibers may comprise other materials in addition to or instead of graphite. It may be found useful for base 100 to include a

material that is the same as the material that is to be thermally coupled to base 100. It may also be found useful to coat the thermal fibers with a flexible covering or adding flexibilizing or toughening agents to the fibrous material.

For one embodiment of the present invention, length 110 and width 111 of base 100 of interface 105 of Figure 1 are in the range of approximately 0.5 and 5 inches, but may conceivably be any size. The length and width of the base are selected to provide a sufficient coupling between the interface and the IC, or other heat generator, to which the interface is to be directly, thermally coupled. For one embodiment of the present invention, the edge at the perimeter of base 100 overhangs the boundaries that define the perimeter of fibers 101. For an alternate embodiment, one of more boundaries of fibers 101 are flush with the edge of the base.

For one embodiment of the present invention, thickness 113 of base 100 of interface 105 of Figure 1 is in the range of approximately 1 to 250 mils or 1 to 25 mils, but may conceivably be any thickness. The base is manufactured to be thick enough to provide a sufficient substrate into which each of fibers 101 may be securely embedded, as demonstrated by fiber 103 in the blowup view, and to provide an adequate surface to which a heat dissipater may be securely bonded. The base is also kept thin enough, however, to reduce the thermal resistance between the fibers and the heat dissipater. For one embodiment of the present invention, base 100 is formed integrally with the heat dissipater. For example, the fibers may be embedded directly into a thermal spreader. Fibers 101 are embedded into base 100 by an amount that provides for secure attachment to the base yet reduces thermal resistance between the fibers and the heat dissipater to be bonded to the base. For one embodiment of the present invention, the ends of fibers 101 protrude through the upper surface of base 100. For another embodiment, the ends of the fibers terminate within the bulk of the base.

For one embodiment of the present invention, length 112 of each of fibers 101 of Figure 1 is less than approximately one inch, but may conceivably be any length. Length 112 of fibers 101 are manufactured to be short enough to reduce the thermal resistance of the fibers b tween the IC and the heat

dissipater, yet long enough to provide adequate flexibility of the fibers to accommodate warping of the IC. Similarly, the fibers are manufactured to be thick enough to provide adequate durability and thermal conductance, yet thin enough to provide adequate packing density and flexibility. For one embodiment of the present invention, fibers 101 are frayed, as demonstrated by individual fiber 102. Fraying the end of the fiber may be found to improve thermal contact with the IC, reducing thermal resistance.

Figure 2A is a cross-section of a thermal interface used in a thermal conduction system in accordance with one embodiment of the present invention. IC 202 is coupled to circuit board 200 via solder balls 201. The thermal interface comprising thermally conductive, flexible, parallel, graphite fibers 203 embedded into copper base 204 is in direct thermal contact with a surface of IC 202 at one end of the fibers. A surface of copper base 203 is bonded to heat dissipater 205. Heat dissipater 205 includes a series of fins to increase the surface area of the dissipater, thereby increasing thermal dissipation efficiency.

Fibers 203 of Figure 2A are not embedded into the surface of IC 202 but rather are slightly compressed onto the surface, allowing for some limited freedom of movement along the surface. Under the compression, fibers 203 bend enough to ensure constant, direct, thermal contact with IC 202 despite warpage of IC 202. For one embodiment of the present invention, a thermal grease resides at the interface of fibers 203 and IC 202. This thermal grease is held between fibers 203 of the interface and may improve the thermal coupling between fibers 203 and IC 202. For an alternate embodiment of the present invention, the ends of fibers 203 are embedded into the surface of IC 202 to improve the thermal coupling between the IC and the fibers.

The bond between copper base 204 and the surface of heat dissipater 205 of Figure 2A is a solder bond formed by soldering the dissipater to the surface of the base. Alternatively, the bond may be a molecular bond formed by sintering base 204 to dissipater 205 at a temperature high enough to form covalent bonds at the interface. For an alternate embodiment of the present invention, the dissipater 205 is thermally coupled to base 203 by simply

placing the two surfaces in direct thermal contact with each other with a thermal grease applied at the interface.

Figure 2B is the cross-section of Figure 2A during operation of the IC. As IC 202 heats up, its surface flattens as shown. Because fibers 203 are flexible and are compressed against the surface of IC 202, the ends of fibers 203 maintain contact with the surface of IC 202 even though the surface of the IC changes its planarity due to heating. Thus, a good thermal coupling between fibers 203 and IC 202, exhibiting a low thermal resistance, is maintained with IC 202 throughout the operation of the IC. After IC 202 ceases operation and cools off, its surface may again become warped, as shown in Figure 2A, and fibers 203 flex to accommodate the IC surface.

Note that a thermal interface such as that described above may be adapted for use in coupling nearly any heat generator to any heat dissipater. For example, a thermal interface may be used to connect a thermal block, which generates heat as a result of conducting the heat from an IC, to a heat pipe, which dissipates the heat by transporting it to a remote location. As another example, a thermal interface such as that described above may be used to connect a first heat pipe to a second heat pipe. Note that in accordance with this embodiment of the present invention, the thermal interface may be curved to accommodate the curved surfaces of the heat pipes. Also, in accordance with one embodiment of the present invention, a thermal interface such as that described above may be used to thermally couple virtually any non-planar surface to a relatively planar or smoothly curved surface.

For example, Figure 3 is a cross-section of a thermal interface used in a thermal conduction system in accordance with another embodiment of the present invention. Heat generator 302 has a rough, non-planar surface as shown. Thermally conductive, flexible, parallel, graphite fibers 303 flex and bend to conform to the surface of heat generator 302, making highly thermally conductive contact therewith. Thermal grease may additionally be used at this interface to improve thermal coupling. Fibers 303 conduct heat generated by heat generator 302, and efficiently transport this heat to base 304 into which

fibers 303 ar embedded. base 304 is bonded to the curved surface of heat dissipater 305, which may be a heat pipe, heat sink, or heat spreader.

As another example, Figure 4A shows a thermal conduction system in which two heat pipes, 400 and 410, include thermal interfaces 405 and 415, respectively. These thermal interfaces are used in conjunction with thermal coupler 420 to form the coupled heat pipes of Figure 4B. Thermal interface 405 includes base 407, into which fibers 406 are embedded, entirely wrapped around and soldered to an extended portion of heat pipe 400. Thermal interface 415 includes base 417, into which fibers 416 are embedded, entirely wrapped around and soldered to an extended portion of heat pipe 410. Heat pipe 400, including thermal interface 405, is inserted into one end of coupler 420, and heat pipe 410, including thermal interface 415, is inserted into the other end of coupler 420.

For an embodiment in which heat pipe 400 is thermally coupled to the heat generator of a computer system and heat pipe 410 is thermally coupled to the heat dissipater, fibers 406 conduct heat from heat pipe 400 and efficiently transport this heat to thermal coupler 420. Fibers 416 conduct the heat from coupler 420 and efficiently transport this heat to heat pipe 410. Thermal grease may be used at the interface between the fibers and coupler 420. For an alternate embodiment of the present invention, the thermal interfaces are bonded to the coupler rather than to the heat pipes. For example, the base of the thermal interface may be bonded to the inner surface of coupler 420 with the fibers extending inward from the base to thermally contact the outer surface of the heat pipes or an extended protrusion from the heat pipes. In accordance with one embodiment of the present invention, coupler 420 is a simple thermally conductive slip or another heat pipe.

For another embodiment of the present invention, a single thermal interface is used to couple one heat pipe to another either directly or via a removable coupler. For example, coupler 420 may be formed integrally with either heat pipe 400 or 410, obviating the need for the thermal interface attached to that heat pipe. For another embodiment, coupler 420 may be formed having a diameter that is larger than the diameter of heat pipe 400 or

410, eliminating the needed for the extended, narrow protrusions form the heat pipes.

This invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident to persons having the benefit of this disclosure that various modifications and changes may be made to these embodiments without departing from the broader spirit and scope of the invention. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

CLAIMS

What is claimed is:

1. A thermal interface comprising:

   a plurality of flexible, parallel, thermally conductive fibers having a first end and a second end, the first end being open; and

   a thermally conductive base into which the second end of the fibers are embedded.

2. The interface of claim 1, further comprising thermal grease disposed between the fibers.

3. The interface of claim 1, wherein the fibers have a length of less than approximately one inch.

4. The interface of claim 1, wherein the fibers are frayed at the second end.

5. The interface of claim 1, wherein the base has a thickness in the range of approximately 1-250 mils.

6. The interface of claim 1, wherein the base has a width and length between approximately 0.5 and 5 inches.

7. The interface of claim 1, wherein the fibers comprise graphite.

8. The interface of claim 7, wherein the fibers have a length of less than approximately one inch, the base comprises copper, and the base has a thickness in the range of approximately 1-250 mils and a width and length between approximately 0.5 and 5 inches.

9. A thermal conduction system to conduct heat from a heat generator to a heat dissipater, the system comprising:

   a first surface;

a plurality of flexible, parallel, graphite fibers having a first end and a second end, the first end being in direct, thermal contact with the first surface; and

a base into which the second end of the fibers are embedded.

10. The system of claim 9, further comprising thermal grease disposed between the fibers.

11. The system of claim 9, further comprising a second surface thermally coupled to the base by a bond.

12. The system of claim 11, wherein the bond is selected from a group consisting essentially of a solder bond and a molecular bond.

13. The system of claim 12, wherein the base comprises copper.

14. The system of claim 9, wherein the first end has freedom of movement along the first surface.

15. The system of claim 9, wherein the fibers have a length of less than approximately one inch.

16. The system of claim 11, wherein the first and second surfaces are surfaces of first and second heat pipes, respectively.

17. A computer system comprising:

an IC;

a plurality of flexible, parallel, graphite fibers having a first end and a second end, the first end being in direct, thermal contact with the IC;

a copper base into which the second end of the fibers are embedded; and

a heat dissipater bonded to the base.

18. The system of claim 17, wherein the IC is a processor.

19. The system of claim 17, wherein the first end has freedom of movement along a first surface of the IC.

20. The system of claim 17, wherein the fibers have a length of less than approximately one inch.

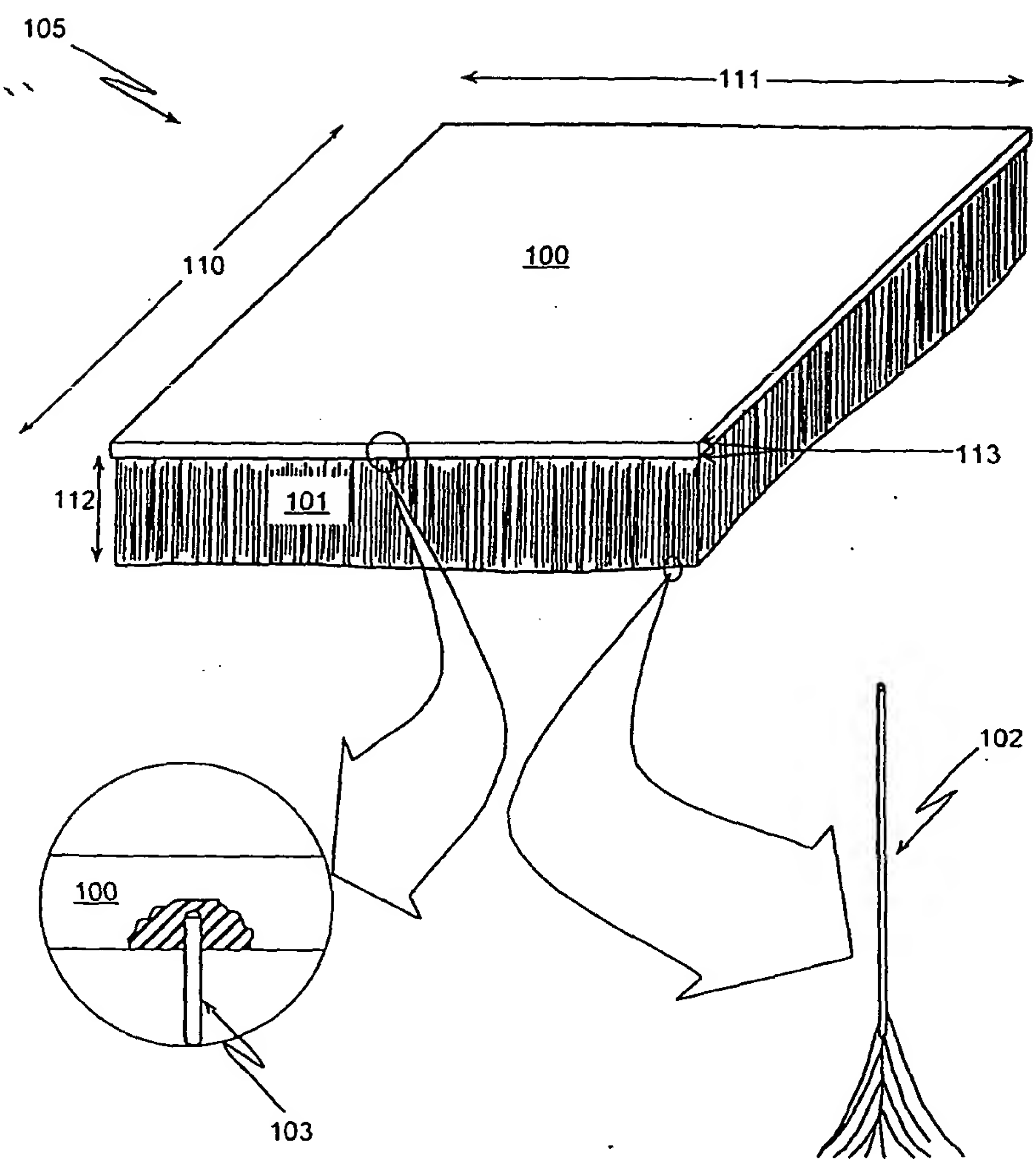

Figure 1

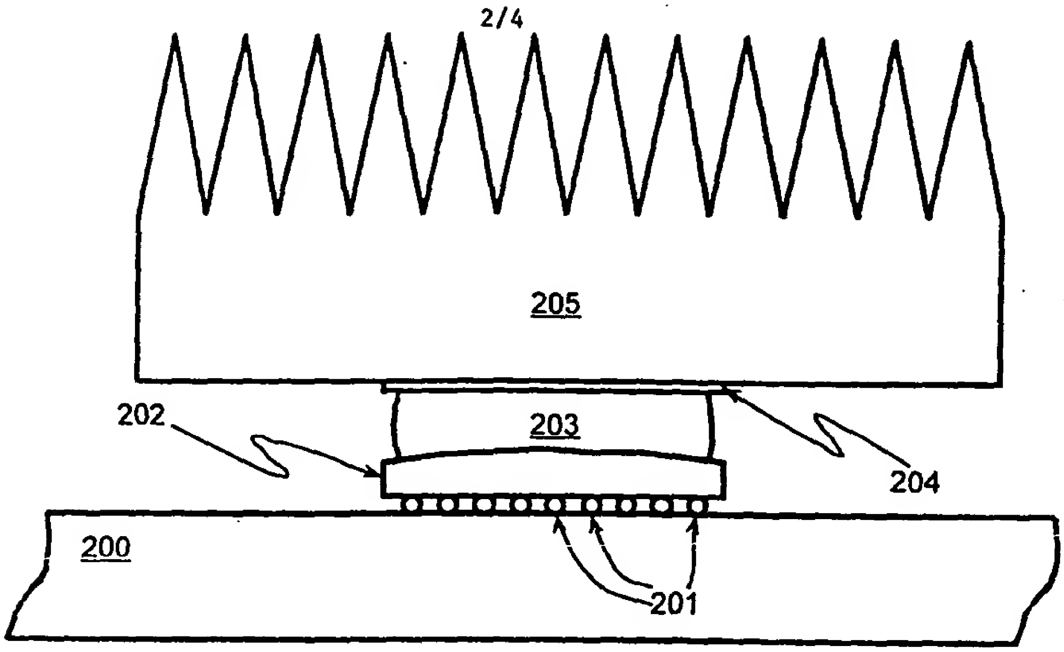

Figure 2A

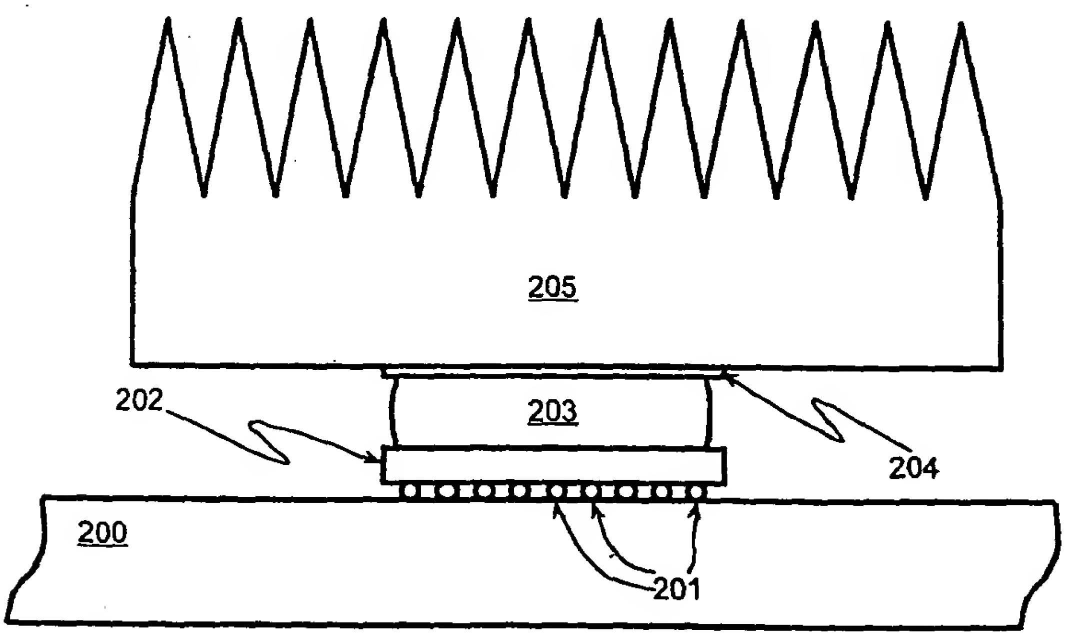

Figure 2B

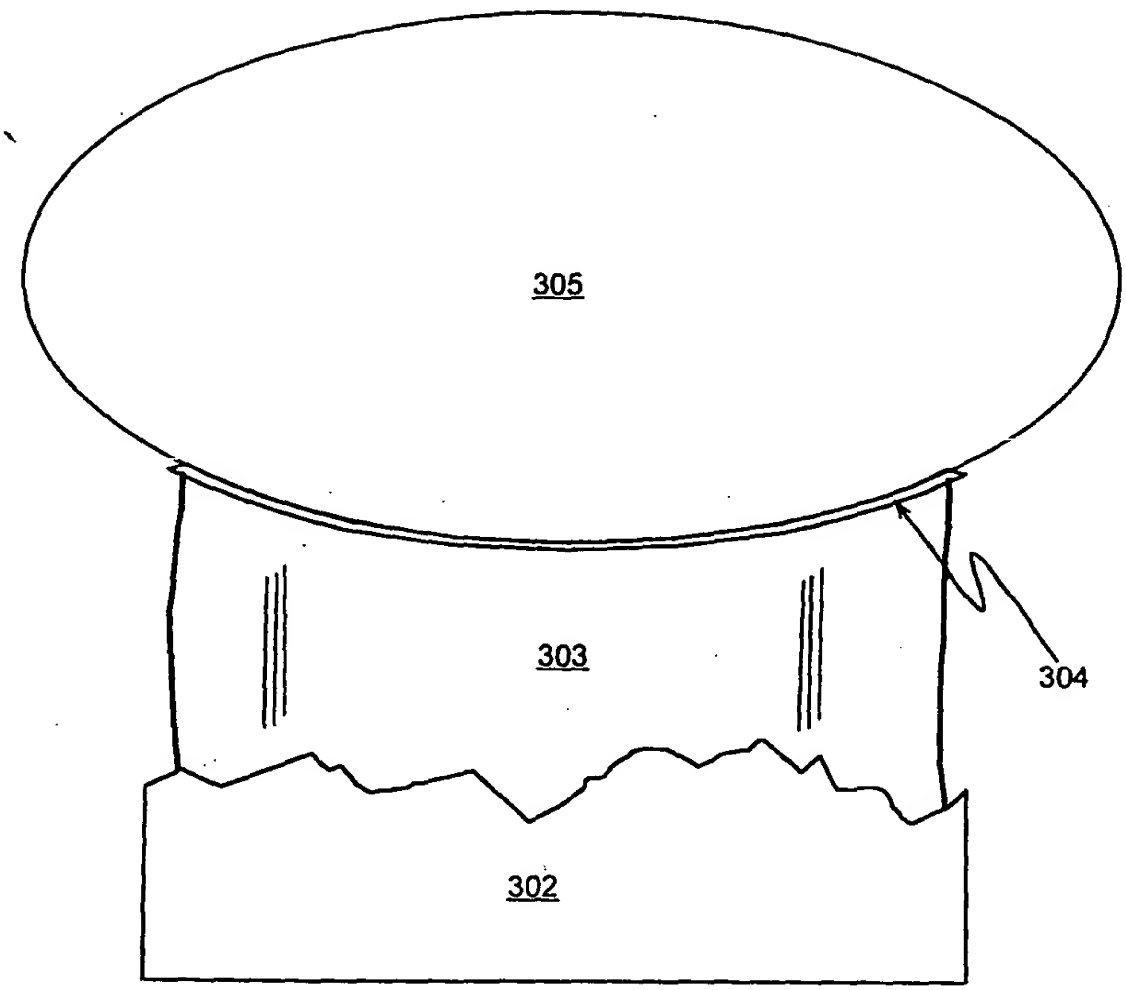

Figure 3

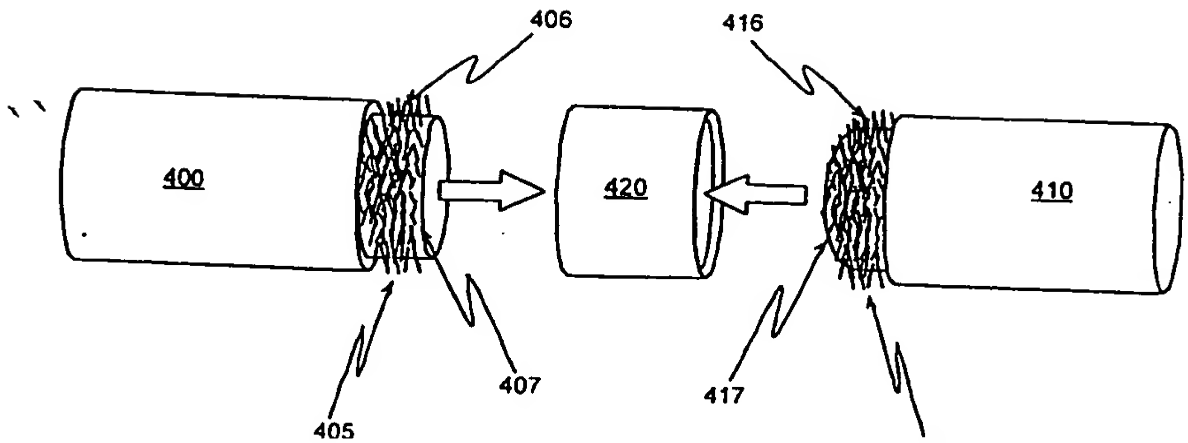

Figure 4A

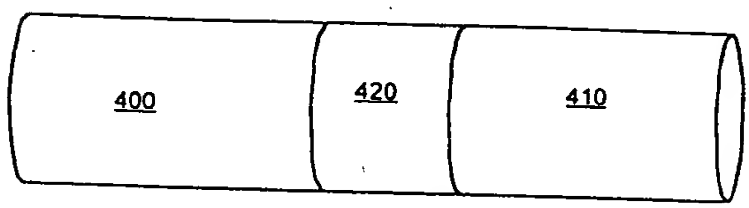

Figure 4B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/26620

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) :H05K 7/20
US CL :361/704, 702, 717, 710; 257/707, 709, 711; 174/16.3; 165/80.3
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60/527; 165/80.2, 80.4, 165, 185;

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
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Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,390,734 A [Voorhes et al] 21 February 1995 (21.02.95) all	1-20
X	US 4,765,139 A [Wood] 23 August 1988, (23.08.88) Figs.1-4, col.3, lines 18 to 37	1, 3, 5-9, 11, 14, 15, 17-20
X	US 5,520,976 A [Giannetti et al] 28 May 1996 (28.05.96), col.7, lines 20 to 25; col.12, lines 22 to 30	2, 10
X	US 4,446,916 A [Hayes] 08 may 1984 (08.05.96) all	4
X	US 5,528,456 A [Takahashi] 18 June 1996 (18.06.96) all	11, 13

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
04 FEBRUARY 2000	01 MAR 2000

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y/P	US 5,847,925 A [Progl et al] 08 December 1998 (08.12.98) all	16
Y	US 5,150,748 A [Blakman et al] 29 September 1992 (29.09.92) all	16
A	US 4,057,101 A [Ruka et al] 08 November 1977 (08.11.77) all	1-20
A	US 5,316,080 A [Banks et al] 31 May 1994 (31.05.94) all	1-20
A	US 5,224,030 A [Banks et al] 29 June 1993 (29.06.93) all	1-20